



~~RESTRICTED~~

STAT

when the furnaces were running smoothly. Results of these tests were correlated to the productivity of the heats from which slag samples were taken. Results are tabulated and plotted.

Viscosity of Synthetic Slags of Ternary Systems  $\text{CaO-FeO-SiO}_2$  and  $\text{MnO-FeO-SiO}_2$  to Which Are Added Chromium Oxide, Magnesium Oxide, or Liquefiers," S. P. Leyba, Ye. P. Komar

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol III, 1941 (Pub 1945), pp 32-56

First slags containing no  $\text{MgO}$  gave viscosity vs temperature curves characteristic of short slags. As the quantity of  $\text{MgO}$  added to these slags increased, the straight portions of these curves shortened, and the temperature at which transition into heterogeneous zone occurred increased. Viscosity vs temperature curves for final slags to which various quantities of  $\text{MgO}$  were added resembled similar curves for long slags. Liquefaction interval induced by  $\text{MgO}$  depends entirely on the chemical composition of the slag. Addition of  $\text{MgO}$  shortens the liquefaction interval and shifts it to higher temperatures. Effect of  $\text{Al}_2\text{O}_3$  was that good fluidity was obtained with various quantities depending on the composition of the system; however, no definite rule of behavior was established. Liquid interval is affected only slightly by addition of  $\text{Al}_2\text{O}_3$  but is shifted appreciably toward lower temperatures. Study of the effect of  $\text{Cr}_2\text{O}_3$  on the viscosity of the two ternary systems presented considerable difficulties; one of these was temperature limitation. Effect of  $\text{Na}_2\text{O}$  on viscosity was greater where the  $\text{SiO}_2$  content was smaller. Characteristics of the viscosity vs temperature curves are insignificantly affected by  $\text{Na}_2\text{O}$ . Effect of  $\text{CaF}_2$  was also more pronounced where the  $\text{SiO}_2$  was smaller. Composition of the slags studied and the respective viscosities are tabulated.

"Viscosity and Crystallization of Glasses and Slags," A. D. Sokol'skiy

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol III, 1941 (Pub 1945), pp 57-60

It was observed that within certain temperature ranges the viscosity curves of molten slags diverge, forming a fan. These temperature ranges were near the melting point of the slags. The divergence could not be ascribed to faulty instrument and was rather due to the nature of the medium. At these temperatures the slags were no longer true liquids, as they were at higher

- 2 -

~~RESTRICTED~~  
FOR OFFICIAL USE ONLY~~RESTRICTED~~

~~RESTRICTED~~

STAT

temperatures, but they were colloidal solutions. The transition point for glass pointed out by Le Chatelier, Morey and Bowen, and English is considered to be the melting point of glass. Hitherto the melting point of glass was determined only by thermal analysis. At the present viscometry is relied upon for such determinations. The point on a viscosity curve where the curves begin to fan out is the point of transition from a homogeneous phase to a heterogeneous one, and the point where crystallization of the molten glass commences.

"Temperature-Viscosity Relation of Molten Glasses and Salts," K. S. Evstrop'ev

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol III 1941 (Pub 1945), pp 61-5

General discussion of the temperature-viscosity relation of molten glasses and salts. Formulas developed by Waterton and others contain many constants, making their use difficult. New formula is suggested,  $\log \eta = A + (B/T^2)$ , which although less accurate is easier to use. A and B, the constants in this formula, are found by plotting  $1/T^2$  vs  $\log \eta$ . The formula was tested on many samples and was found to be correct at temperatures above the liquidus. Below the liquidus line this formula does not hold. For the relation between  $\eta$  and composition is suggested the expression  $\log \eta = a + bC$  where a and b are constants, and C is the concentration of one of the components.

"Remarks on the Connection Between Viscosity and the Diagram of Melting," K. G. Kumanin

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol III, 1941 (Pub 1945), pp 66-9

Discussion of the system  $\text{Na}_2\text{O}-\text{BaO}-\text{SiO}_2$ . Phase diagram of this system shows a syncline along the contact lines of  $\text{Na}_2\text{O}-\text{SiO}_2$  and  $\text{BaO}-\text{SiO}_2$ . Syncline is coupled with a considerable drop in temperature. By constructing sections of viscosity isotherms with constant content of  $\text{SiO}_2$  there are obtained minima that correspond exactly to this syncline. At 65 mol% content of  $\text{SiO}_2$  this trough occurs at BaO content of approximately 10 mol %. The lower the temperature the smaller is the angle made by the lines. At 1,400° the line is practically straight. The more general type of viscosity isotherm is represented by curves such as are obtained by keeping the  $\text{Na}_2\text{O}$  at 15 mol %. Here as the BaO increases the viscosity isotherm drops. On the phase boundary of such a diagram there is a clear break in all the isotherms. Isocomes of the system were drawn on a phase diagram of this system. It can be seen from the resulting diagram that the

- 3 -

~~RESTRICTED~~

FOR OFFICIAL USE ONLY

~~RESTRICTED~~

~~REDACTED~~

STAT

location of the isocomes on the diagram is definitely connected with the nature of the diagram.

"Viscosity and Linear Crystallization Velocity of Glasses," A. A. Leont'yeva

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol III, 1941 (Pub 1945), pp 70-7

Rate of crystallization was studied on seven compositions of the system  $\text{Na}_2\text{O}-\text{SiO}_2$  in which the  $\text{SiO}_2$  content ranged from 60-80% by weight. Four of these compositions crystallized as  $\text{Na}_2\text{O} \cdot 2\text{SiO}_2$  which separated in the form of spherulites. Temperature ( $t$ ) vs velocity of crystallization ( $v$ ) for four glasses showed maxima for  $v$  lying near one another. The liquidus temperatures of these glasses are also near one another. The highest rate of crystallization was for glass containing the largest quantity of  $\text{Na}_2\text{O}$ . Correlating the rate of crystallization and the viscosity at temperatures below the maximum rate of crystallization showed the two to be inversely proportional. By plotting fluidity vs  $v$ , the line obtained is straight. Calculated and experimental rates of crystallization are compared.

"Viscosity of Industrial Glasses," M. V. Okhotin

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol III, 1941 (Pub 1945), pp 78-81

Viscosity of bottle, sheet, packing, and other technical glasses was determined in an improved Volarovich viscometer (described). The glasses studied were 5-component systems containing  $\text{SiO}_2$  69-75,  $\text{Al}_2\text{O}_3$  1-5,  $\text{CaO}$  5-11,  $\text{Na}_2\text{O}$  12-16, and  $\text{MgO}$  3%. From the experimental data the following relations were expressed as curves:  $\log \eta$ - $t$ ,  $\log \eta$ -composition (isotherms), and temperature-composition at constant  $\eta$ . By considering  $\text{CaO} + 3\%$  of  $\text{MgO}$  as one component, the results were constructed on a 4-component diagram on which the values of  $\text{Na}_2\text{O}$  were placed on the x-axis,  $\text{CaO} + 3\%$  of  $\text{MgO}$  on the y-axis,  $\text{Al}_2\text{O}_3$  on the z-axis, and temperature on the t-axis. Calculated and experimental data (tabulated) were in good agreement.

"Viscosity-Free Flow of Helium II," P. L. Kapitza

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 8-13

Lecture.

"Quantum Theory of the Superfluidity of Helium II," L. D. Landau

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 14-17

Lecture.

- 4 -

~~REDACTED~~

FOR OFFICIAL USE ONLY

~~REDACTED~~

STAT

"Present Status of the Theory of the Viscosity of Liquids and Its Practical Applications," M. P. Volarovich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 18-23

Review with 55 references up to 1941.

"Viscosity of Liquids and Transfer of Momentum by Waves," M. P. Shirokov, Voronezh State U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 35-42

In contrast to Brillouin's conclusion that, owing to absorption, transfer of momentum through waves runs counter to viscosity, a theory is developed that derives viscosity from that very mechanism. With  $U_v$  = energy density of waves of frequency  $\nu$ ,  $\beta_v$  and  $\alpha_v$  = scattering and absorption coefficient, respectively,  $a$  = sound velocity, one obtains  $\eta = 1/3 \int U_v (\alpha_v - \beta_v) dv$ , which on integration leads to  $\eta = \rho U/3a$ , where  $U$  = energy density of all molecular vibrations and  $\rho$  = mean path of the wave. By the same theory, one derives for the heat conductivity  $\lambda = 1/3 \rho C_v l$ , where  $\rho$  = density and  $C_v$  = heat capacity at constant volume. This is identical with Debye's formula except for the factor  $1/3$  instead of  $1/4$ .

"Anomalous Phenomenon in the Flow of Liquids Through Fine Pores of Rigid Filters," B. V. Deryagin, N. A. Krylov

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 52-3

The rate of flow of water through porous ceramic and carbon filters was measured as function of the pressure  $P$  applied by means of a mercury column. No anomalies were observed with pores of 0.3 micron diameter or greater, the rate of flow being directly proportional to  $P$ . Addition of isocetyl alcohol or of isovaleric acid has no effect. With pores of 0.14 micron diameter, the flow follows Poiseuille's law only at relatively high  $P$ . At lower pressures, the flow is no longer viscous but nearly plastic in character, following approximately Bingham's law. The intercept on the  $P$  axis, corresponding to zero rate of flow, is longer the smaller the diameter of the pores. In this region (small pores and low pressures) anomalies are also encountered on addition of extraneous substances; thus, with 1% glucose, the rate of flow drops sharply even though the bulk viscosity is not noticeably altered at that concentration. Assumption of a tightening effect on the pores as result of adsorption does not adequately account for the effect.

~~RESTRICTED~~

STAT

Impregnation of the pores of ceramic filters with benzene solution of oleic acid, leaving after evaporation of the solvent, a film of oleic acid on the walls of the pores, results in sevenfold increase in the rate of flow of pure water; the effect, however, is not permanent. It is tentatively explained by assuming a decrease in the viscosity at the interface boundary due to dehydration by oleic acid. Carbon filters show anomalies even with pores of diameter of the order of  $0.7\mu$ ; addition of isoamyl alcohol and of isovaleric acid resulted, respectively, in four- and fivefold increases in the rate of filtration.

"Effect of a Constant Electric Field on the Viscosity of Liquids," A. K. Chernyuk, Phys Inst, Odessa State U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 62-7

For the study of the action of transverse electric field, differential setup is described involving two identical capillaries, fed from common reservoir flask and collecting vessels placed on two plates of analytical scale. One of the capillaries is placed in electric field up to 40,000 v/cm by means of external electrodes. Effects observed with this arrangement, however, show the predominant effect of the convective motion arising in the liquid under the action of the electric field and masking the true change of viscosity. To allow for the effect due to convection, the phenomenon was studied in longitudinal fields, up to 8,000 v/cm, in horizontal capillaries. Since the convective effect depends on the direction of the field, and effect of the electric field on the viscosity is independent of the field direction, the two effects are determined separately by inverting the field from parallel to antiparallel with regard to the direction of flow. Experimental observations are described.

"Effect of Elastic Vibrations on the Viscosity of Liquids," P. I. Dombrovskiy, Phys Inst, Odessa State U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 68-70

Test apparatus and experimental conditions are described. Horizontal viscometer capillary was used. At room temperature, with ethyl alcohol and amyl alcohol, supersonic vibrations decrease the viscosity by 10-15% depending on the intensity. The effect diminishes somewhat at higher temperatures. Slight decrease in viscosity remains when vibrations are turned off,

~~RESTRICTED~~

~~RESTRICTED~~

STAT

showing some signs of delayed action. Low-frequency audible acoustic vibrations depress viscosity slightly within limits of experimental error. In water, a 4-5% decrease in viscosity is found in supersonic vibrations, the effect diminishing with rising temperature; there is a hint of delayed action; audible frequencies have no effect on viscosity. Nitrobenzene is not affected by low-frequency waves; supersonic vibrations cause  $\eta$  to increase somewhat. Benzene shows the same effect, a distinct increase of  $\eta$  to a much higher degree; it is 3% or more in supersonic waves; no effect is present at audible frequencies. In connection with the problem of the existence of increased viscosity in the layer contiguous to the wall in undercooled liquids and the effect of elastic vibrations on their rate of crystallization, study was made of the viscosity of undercooled salol, down to 28°, below the melting point. Results described.

"Temperature Dependence of the Viscosity of Liquids,"  
P. P. Kobeko, E. V. Kuvshinskiy, N. I. Shishkin,  
Leningrad Phys Tech Inst

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov"  
Vol II, 1944, pp 71-5

The currently admitted linear dependence of  $\log \eta$  (viscosity) on  $1/T$  (absolute temperature), of the form  $\log \eta = A + U/RT$ , requires that the quantities  $A$  and  $U$  be constant over the whole temperature interval. Admission of a thermal variability of  $U$  makes a comparison of the underlying theories with experimental data impossible. Curves of  $\log \eta$  in terms of  $1/T$  over wide temperature interval were constructed for series of substances of widely different nature: diethyl ether, ethyl alcohol, propyl alcohol, isobutyl alcohol, glycerol, rosin,  $HCl$ ,  $H_2SO_4$ ,  $H_2PO_4$ ,  $B_2O_3$ , silicate glass,  $SiO_2$ ,  $BiCl_3$ ,  $LiNO_3$ ,  $NaCl$ ,  $Cd$ ,  $Sn$ ,  $Hg$ , air. The graph shows divergent fan of curves, somewhat shifted relative to one another. Curves are steeper the higher the softening point of the substance; thus the steepest slope belong to the curve of silicate glasses. For each curve, a relatively slight temperature dependence is found in regions of low  $\eta$ ; as the liquid thickens, the slope becomes steeper. In the steeper portions, the curvature is pronounced over intervals other than very narrow ones. There are no discontinuities, and consequently there is no justification for representing the curves as composed of two intersecting linear portions. Although for certain substances such as metals and fused inorganic salts, data are available only over a relatively short temperature interval, their fragmentary curves do fit into the general picture and appear to prolong those of the other substances. All curves fan out toward higher viscosities and lower temperatures.

~~RESTRICTED~~

~~RESTRICTED~~

STAT

"Generality of Types of Viscosity Isotherms in Binary Liquid Systems," N. A. Trifonov, Phys Chem Lab, Rostov-on-Don State U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 76-84

For rational binary systems, that is for systems forming a nondissociating compound, there are nine possible types of viscosity-composition isotherms, all of them showing a sharp singular point. Depending on whether the viscosity of the compound is higher, lower, or intermediate between those of the components, the singular point is a maximum, a transition point, or a minimum. Depending on whether in the compound formation the number of molecules decreases, remains unchanged, or increases, the two branches of the curve are convex to the axis of abscissas, rectilinear, or concave. For irrational systems, involving part dissociation of the compound through chemical interaction and disappearance of a sharp singular point, the number of possible types is reduced to seven. Of the nine possible rational types, only three are reliably realized. Examples of the different types are given.

"S-shaped Viscosity Diagrams," M. I. Usanovich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 85-8

Several binary systems were analyzed to ascertain whether S-shaped  $\eta$  (viscosity)-composition curves actually are the result of a disappearance of the maximum at a sufficiently high temperature, as was claimed by N. S. Kurnakov for the system  $C_6H_5SbCl_3$ . To this end, the temperature derivative  $d\eta/dt$  was plotted against composition for the system  $C_6H_5NO_2-H_2SO_4$ , above and below the melting point of the compound. Values of  $d\eta/dt$  increase with rising temperature and show no tendency to pass through zero. Consequently, there is a hint of maximum of  $\eta$  at lower temperature. Same was found for the systems  $Et_2O-AsCl_3$  and  $CHCl_2COOH-HClO_4$ . Correct interpretation of S-shaped curves is that one of the components is associated to higher degree than the compound the formation of which results in a simplification of the composition of the system. Such systems cannot have a maximum no matter how much the temperature is lowered. Conclusion: S-shaped  $\eta$  curves cannot be interpreted by disappearance of maximum due to raised temperature.

"The Maximum of Viscosity of Irrational Systems," V. V. Udovenko, Phys Chem Lab, Central Asia State U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 89-93

- 8 -

~~RESTRICTED~~



~~RESTRICTED~~

STAT

Comparison with melting diagrams has shown that in "irrational" binary systems the maximum of the viscosity curves in terms of composition does not occur at the composition corresponding to that of the compound formed. Usual interpretation in terms of dissociation of the compound is subject to caution. Diagram of system A-B involving a compound C can be constructed from the part diagram A-C, with a maximum, and C-B. Displacement of the maximum in the resulting A-B curve is due to interaction of the compound C and the component A and not to dissociation. This is further borne out by the observation that the maximum does not tend to draw closer to the stoichiometric composition as the temperature approaches the melting point, which would have to be the case if displacement were due to dissociation in liquid phase. The shift sometimes is found to persist below the melting point in undercooled liquid. Several experimental systems are described.

"Some Aspects of Viscosity of Liquids," A. I. Bachinskiy, Lomonosov State U, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol. II, 1944, pp 104-6

In terms of temperature  $t$ , many liquids obey the simple law  $\eta = A/(t + a)^3$ , where  $A$  and  $a$  are constants; that is, the plot of  $\sqrt[3]{\eta}$  against  $t$  is a straight line. Discontinuity of slope observed in certain cases, for example for water at  $30^\circ$ , may indicate some sort of transition; that this is real is shown by the fact that water also has minimum of heat capacity at that temperature. For nonassociated, or "normal" liquids,  $\eta = c/(v-b)$  where  $v$  = volume,  $b$  = limiting volume,  $c$  = constant, termed the "modulus of viscosity." Linearity ceases to hold for associated liquids.

"Viscosity of Mineral Oils," N. I. Chernozhukov

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol. II, 1944, pp 120-7

Conclusions attributing a determining role in the viscosity of mineral oils to their content in either aromatic or naphthenic hydrocarbons are erroneous. Such conclusions were based on extractions with selective solvents; these are shown to extract not a definite class of compounds but mainly polycyclic hydrocarbons with short lateral chains which have the highest values of viscosity  $\eta$  and low values of the viscosity index; these hydrocarbons can be either aromatic, naphthenic or aromatic-naphthenic. The  $\eta$  of an oil increases with its content in polycyclic hydrocarbons, the number

~~RESTRICTED~~

~~RESTRICTED~~

STAT

of rings being decisive; the length and the number of lateral chains have a further increasing effect on  $\eta$ . Examples are given. Strongest variations of  $\eta$  on lowering the temperature are found with polycyclic hydrocarbons with short lateral chains, irrespective of their nature; compounds with few rings and long lateral chains show lower viscosity temperature coefficient. Elimination of the latter hydrocarbons through far-reaching deparaffination entails a lowering of mobility at low temperature. Absence of long lateral chains which screen the rings favors molecular association, which is responsible for the strong increase of  $\eta$  at low temperatures and its rapid fall at higher temperature. Inasmuch as long molecules are more easily oriented in the direction of the flow, mobility at low temperatures will be favored by elimination of polycyclic hydrocarbons with short lateral chains. Consequently, distillate oils have better mobility at low temperature than residual oils even if highly purified.

"New Viscometer for the Determination of the Viscosity of Petroleum Products at Low Temperatures,"  
Yu. A. Pinkevich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov"  
Vol II, 1944, pp 141-4

New viscometer is usable at temperatures even below  $-35^{\circ}$  and involves no Hg. It consists of U-shaped tube one branch of which has capillary part at its lower end and widens towards the top. The other branch has a similar widening at the same height, and two spherical spaces farther up. Oil is poured into the apparatus up to a certain level on the widened parts; the branch having the two spherical sections is filled with dyed MeOH or EtOH. The two branches are connected alternately with a source of pressure by means of three-way stopcock. When the first branch is put under pressure, the oil is squeezed through the capillary and lifts the alcohol until it fills the lower of the two spheres. With the pressure reversed, the oil and alcohol flow back. Viscosity of the oil is determined by average time of efflux in both directions; the effect of alcohol is thus eliminated.

"Viscosity and Mobility of Oils at Low Temperatures,"  
V. K. Limar, V. G. Sidorov

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov"  
Vol II, 1944, pp 145-54

An apparatus was constructed in which the behavior of motor oil at low temperature is investigated under conditions closely approximating those of actual service.

- 10 -

~~RESTRICTED~~~~RESTRICTED~~

~~RESTRICTED~~~~RESTRICTED~~

STAT

Oil is pumped from a brass tank through a pipe and stopcock and is collected and weighed. Measurements at three pressures of the reducing valve showed the rate of feeding to be linear. Subsequent measurements were made at fixed pressure; results are expressed in Q (grams of oil per revolution of the pump); limiting temperature of mobility  $t'$  is the temperature at which Q becomes practically zero. Results of measurements on two specimens of petroleum oil show that  $t'$  does not depend on the freezing temperature but depends rather on the high-temperature viscosity. Tests on other automobile lubricating oil, purified oil, synthetic oils, and castor oil are reported.

"Parameters Characteristic of the Flow of Aviation Oils at Low Temperatures," S. L. Peisakhodina, R. N. Shmeyerova, G. S. Taramanyan

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 155-60

The minimum temperature  $t'$  of mobility of lubricating oils dispensed to the motor by a rotating-pump apparatus, defined as the lowest temperature at which in one revolution of the pump not less than 0.08 gr of oil is ~~passed~~, was compared with the freezing point of the oil,  $t_f$ , defined by USSR specification by test consisting in heating the oil in test tube to 50° and cooling to the temperature at which the oil will not move for 5 min when the tube is inclined at 45°. On 12 different oils it was demonstrated that  $t_f - t'$  may vary from -19° to +8°. Oils having equal  $t_f$  were found to have greatly differing  $t'$ , and vice versa. Consequently, the freezing temperature is in no way a criterion for the low-temperature mobility of an oil from the point of its feeding to the motor.

"Influence of Additions on the Temperature Dependence of the Viscosity of Lubricating Oils at Low Temperatures," K. S. Ramayya

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol II, 1944, pp 178-87

Transformation of Bingham's equation of plastic flow gives  $\eta_a = \bar{\eta} + f/S$ , where  $\eta_a$  = apparent viscosity,  $\bar{\eta}$  = residual viscosity ( $\bar{\eta} = 1/\mu$  where  $\mu$  = Bingham's mobility),  $S$  = velocity gradient in sec<sup>-1</sup>,  $f$  = limiting shearing stress, being the upper limit of thixotropic flow. Plots of the yield Q (in gr/min) in terms of stress P (in Kg/sq cm) give straight lines, intercept on the P axis corresponding to  $f$ . For an oil freezing at 2° "automobile oil 18,"  $f$  becomes noticeable at as high as +40° and increases with falling temperature.

- 11 -

~~RESTRICTED~~

~~RESTRICTED~~

STAT

While the temperature curve of  $f$  is strongly influenced by additions of 0.5% Al stearate, the mobility  $\mu = \frac{1}{\eta}$  is only very slightly affected. Same was found with additions of alkylated naphthalene and alkylated phenyl phthalate; the latter is more particularly active, 0.5% of it resulting in notable increase of the yield of the lubricant dispensed. Effect of additions is particularly clearly illustrated by graphs in the coordinate system  $\eta_a$ ,  $P$  between  $0^\circ$  and  $-30^\circ$ , on "automobile oil 10." At temperatures below  $-20^\circ$ , only alkylated phenyl phthalate continues to lower  $\eta_a$ , while the action of Parafflow ceases or even is reversed. With selectively purified "automobile oil 18", addition of 0.5% Al stearate lowers both  $f$  and its temperature coefficient. With  $H_2SO_4$ -purified "automobile oil 10", addition of 0.5% Parafflow lowers  $f$  but raises its temperature coefficient; addition of alkylated phenyl phthalate lowers both  $f$  and its temperature coefficient. Artificial and natural resinous additions that lower the freezing point may, at lower temperatures, occasionally cause an increase in  $f$  if their presence raises the temperature coefficient; this does not apply to addition agents containing polar oxygenated groups such as Al stearate which always depress the temperature coefficient of  $f$  at low temperatures.

"Standardization of Methods of Determination of the Viscosity of Petroleum Products," P. M. Golenev

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyzkostei Zhidkost i Kolloid Rastvorov"  
Vol II, 1944, pp 188-91

For the conventional Engler method, USSR specifications permit deviations of 0.5-1.5% corresponding to 4% in centistokes. For low viscosities (1.05-1.2°E) the permissible deviation 1.6-2.0% in Engler degrees corresponds to 7-10% in centistokes. Actual divergence of determinations by various laboratories is often higher than the maximum permissible error. For the same sample (auto oil 18), 14 different control laboratories reported figures in °E diverging by -5.4% to +4.2% from the average, at 50°. Engler's method is not applicable beyond about 130 centistokes. For the conversion of °E into centistokes  $v$ , seven different formulas have been proposed of the form  $v = AE - (B/E)$ . Values of A and B are given. None of these formulas are accurate enough. USSR specification "GOST 33-40" recommends the Ostward-Fenske-Pinkevich viscometer, permitting determinations up to 10,000 centistokes, between  $-20^\circ$  and  $+150^\circ$ ; the permissible deviation for one laboratory is 0.4%, for two different laboratories 0.8%; actual deviations are less than the permissible maximum. Projected standard for low-temperature viscosity keeps deviations down to  $\pm 0.5\%$  at  $-50^\circ$ , 10,000 poises (over 100,000°E). Abandonment in industrial practice of relative units and exclusive adoption of absolute units (poise and stokes) is recommended.

~~RESTRICTED~~

~~RESTRICTED~~

STAT

"Viscosity of Liquid Mixtures," G. P. Luchinskiy

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 41-5

For ideal mixture of two liquid components A and B, the viscosity of the mixture can be expressed by  $\eta = (aC_A + bC_B)/(v - a\omega_A - b\omega_B)$ , where a, b and  $\omega_A, \omega_B$  are, respectively, the weight fractions and limiting volumes of A and B, and v is the specific volume of the mixture;  $v = av_A + bv_B$ ; the constants  $C_A$  and  $C_B$  are, respectively,  $C_A = \eta_A(v_A - \omega_A)$  and  $C_B = \eta_B(v_B - \omega_B)$ . For a nonideal system where neither the specific volume nor the constant C is additive, the correct formula becomes  $\eta = (aC_A + bC_B)e^{k\sqrt{x}}/(v - a\omega_A - b\omega_B)$ , where x is the mole fraction of the component present at the lower concentration and k is a coefficient which for many systems expanding on mixing has the value 0.15; for systems contracting on mixing, the exponent is negative. The formulas are found to be in good agreement in several systems calculated.

"Effect of the Magnetic and Electric Fields on the Viscosity and Molecular Orientation of Anisotropic Liquids," V. N. Tsvetkov, Phys Inst, Leningrad U

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 47-57

In the magnetic field, at constant rate of flow (expressed by the pressure difference P in gr/sq cm), the viscosity of para-azoxyanisole (expressed by the time of flow through the capillary,  $\tau$ ) at 120°, rises with the field intensity H up to about 10,000 oersteds and remains constant from there on. Plots of the relative change  $\Delta\tau/\tau$  due to the magnetic field, against the pressure difference P, show the effect to decrease systematically with increasing P. At high rates of flow, the effect of the magnetic field becomes unnoticeable. Saturation value of  $\Delta\tau/\tau$  is practically the same for different values of P. Experiments were made in plane capillary of brass, of very nearly rectangular section; the foregoing observations are valid for a magnetic field perpendicular to the flow but parallel to the velocity gradient; in a field perpendicular to the gradient, that is parallel to the longer side of the rectangular section of the capillary, the effect is much smaller. In longitudinal fields of that intensity,  $\tau$  is somewhat shortened. In longitudinal field or in the absence of magnetic field, Poiseuille's law holds at medium rates of flow. In transverse fields, the law holds only at saturation and above, where orientation of the axes to the molecule parallel to the field is complete. In a transverse electric field parallel to the velocity gradient, the increase of  $\tau$  with increasing electric field strength E is smaller the higher frequency of  $\nu$ . The electric field acts in two ways: as a result of the dielectric anisotropy

- 13 -

~~RESTRICTED~~

~~RESTRICTED~~

STAT

of para-azoxyanisole, the molecule axes are oriented parallel to the field, the effect being independent of the frequency; on the other hand, the field gives rise to a macroscopic motion of the liquid between the electrodes diminishing with increasing  $v$ . Saturation observed in this case does not mean complete orientation of the molecules but indicates equilibrium between the two electric field effects. Measurements of the dielectric constant on flowing para-azoxyanisole in a magnetic field showed that increased rate of flow counteracts and compensates the increase of dielectric constant due to the magnetic field. Statistically, starting from G. B. Jeffery's equation for the moment acting on an ellipsoidal particle in a velocity-gradient field, introducing the moment due to the magnetic and electric field, and disregarding interaction between the particles, one arrives at an expression for the change of the dielectric constant that accounts qualitatively for the observed saturation phenomena. Quantitative agreement is reached upon introduction of term accounting for swarm interaction.

Processes of Viscous Flow in the Deformation of High-Polymer Materials," V. A. Kargin, G. L. Slonimskiy, Karpov Phys Chem Inst, Moscow

\*Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchaniye kosti Zhidkost i Kolloid Reshvorov" Vol I, 1941, pp 117-21

In the stress relaxation of high polymers, orientation of the chains as a whole and that of its individual links do not as a rule coincide. Rate of the latter relaxation process within the chain is determined by the energy of interaction between chain links. Translation of the chains as a whole (flow), depending on the energy of interaction between chains, lags behind the inner stress relaxation process. It only appears in its pure form once the stationary state is established and only then is it permissible to speak of viscous flow. Translational motion of chains can be hindered or suppressed by chain cross-linking as in vulcanization of rubber; the mobility of chain links remaining free, deformation will result in pure elastic effects. Anisotropy of viscosity along and across the chain axis can be of different origin; it can result either from stress relaxation or from viscous flow. The length of the relaxation process within the chain depends on the degree of interaction of its polar groups, specifically on the variability of that interaction with the mutual position of the groups. This variation is small in cellulose but can attain significant values in rubber, as evidenced by the change of specific gravity on deformation and by the Joule heat effect.

- 14. -

~~RESTRICTED~~~~RESTRICTED~~

~~RESTRICTED~~

STAT

~~RESTRICTED~~

"Viscosity of Mineral Oils and Its Temperature Dependence,"  
G. M. Fanchenkov, Gubkin Petroleum Inst, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 139-47

(1) Viscosity formulas of Bachinskiy, Andrade, and Khaykin are analyzed and evaluated. Bachinskiy's formula can be derived from the kinetic gas theory and it does not apply satisfactorily to associated liquids or at temperatures distant from the boiling point, as mineral oils between  $-50^{\circ}$  and  $+150^{\circ}$ . Of the two Andrade formulas, one does not take into account thermal variation of the frequency of molecular vibrations but gives better agreement with experimental data than the other. Khaykin's formula is applicable to liquids near the melting point but requires a change of the numerical values of the constants to be valid at higher temperatures; it is therefore a semiempirical formula. (2) From the point of view of relations between molecular structure and viscosity, analysis of curves of  $\eta$  against temperatures from  $20^{\circ}$  to  $80^{\circ}$ , for 18 different hydrocarbons demonstrates that  $\eta$  of naphthenes is not necessarily higher than that of the corresponding aromatic compounds. The viscosity of hydrocarbons proves to be an approximate additive property only if comparisons are limited to temperatures of equal slopes of the  $\eta$ -temperature curves. (3) Other experimental material on variation of  $\eta$  with pressure is surveyed and discussed.

"The Characteristic of the Temperature Dependence of the Viscosity of Lubricating Oils," M. M. Kusakov, Colloid Electrochem Inst, Acad Sci USSR

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 149-60

Present systems expressing the quality of lubricating oil by a single viscosity index are unsatisfactory. A single index can never be sufficient to characterize the quality with regard to both viscosity level and temperature coefficient. One parameter is needed to define the level at a given temperature and one or two more, depending on the accuracy demanded, to characterize the slope of the curve  $\eta = f(t)$ . The temperature dependence can always be represented in the form of a function of  $\eta$  linear with respect to temperature, namely some function  $\Phi(\eta) = At + B$ , providing two parameters A and B. The choice of the function  $\Phi(\eta)$  amounts to a "straightening" of the temperature curve of  $\eta$  by substituting a function of  $\eta$  linear in temperature, for  $\eta$  itself. If higher accuracy is required, a third parameter C is needed; it must be included in  $\Phi(\eta)$ . Problems of interpolation and of extrapolation, and of classification of lubricating oils, can then be solved with sufficient

- 15 -

~~RESTRICTED~~~~RESTRICTED~~

STAT

accuracy with the aid of nomograms. As a three-constant equation, the Vogel-Fulcher-Tammann formula  $1/\eta = C/(t-t_0) + v_\infty e^{C/(t-t_0)}$  is proposed which, by substituting for  $\eta$  the kinematic viscosity  $\nu = \eta/\delta$  (where  $\delta$  = density), becomes  $\nu = v_\infty e^{C/(t-t_0)}$ . The constant  $v_\infty$  characterizes the viscosity level at an infinitely high temperature; the coefficient  $C$  is that change in temperature for which the kinematic viscosity  $\nu$  would be increased  $e$  times relative to  $v_\infty$ ; at  $C = t-t_0$ ,  $\nu = v_\infty e$ . The constant  $t_0$  represents the temperature at which the viscosity would become infinite. Oils with a high value of  $v_\infty$  have a high "viscosity level"; high values of  $C$  and of  $t_0$  mean a gentle slope of  $d\nu/dt$  and  $d\eta/dt$ , that is relatively slight temperature variation of  $\nu$  and  $\eta$ . From experimentally found values of  $v_\infty$ ,  $C$ , and  $t_0$ ,  $\psi(\nu) = A + B$  can be written in the form  $1/\eta = (v/v_\infty) = (1/C)(t-t_0/C)$ . This equation has been found without exception in good agreement with experimental material.

"True and Extrapolated Viscosity of Lubricating Oils,"  
D. S. Velikovskiy, Gubkin Petroleum Inst, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchen Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I,  
1941, pp 161-72

"True" viscosity is the minimum value of  $\eta$  which at the given temperature corresponds to high velocity gradients  $S$  and does not further decrease with further increasing  $S$ . It was assumed that this value can be obtained by extrapolation to low temperatures by means of empirical relations  $\eta = f(T)$ , such as the formulas of Walther and others. At low temperatures, the value is determined mainly by the dependence of  $\eta$  on  $S$ , and the limiting resistance to motion  $\Theta$ . The two magnitudes are related, at any given common velocity, by  $\log \eta = a \log \Theta + b$ , where  $\eta$  is expressed in poises and  $\Theta$  in dynes per sq cm;  $a$  and  $b$  depend on the chemical composition and colloidal state of the oil. Usual methods of viscometric measurements give in general some sum of  $\eta$  and the static resistance. "Pure"  $\eta$  values can only be determined in an established stationary flow. Curves of  $\log \eta$ , obtained under such conditions of constant flow, for  $S = 100, 1$  and  $0.1 \text{ sec}^{-1}$ , in terms of temperature between  $0^\circ$  and  $-50^\circ$ , are compared with the curves extrapolated by using Walther's formula and with the experimental ("viscometric") curve obtained, down to  $-10^\circ$ , with Ostwald's viscometer, and from  $-10^\circ$  down to  $-50^\circ$ , with modified Lee viscometer. Constant-flow curves, at all  $S$ , are consistently lower than the extrapolated curves at low temperatures. Extrapolated curve of mixture of purified oil lies substantially above that of mixture of purified distillate oils. Neither the Fulcher-Tammann nor the Walther, nor the Tanaka equations are suited for extrapolation down to low temperatures. The discrepancies are due in the main to appearance of additional structural resistance to motion. Viscosities extrapolated by the various formulas are always much higher than the "true" or minimum viscosity.



STAT

"Determination of the Viscosity of Oils at Low Temperatures," A. F. Dobryanskiy, A. P. Sivertsev, I. Ya. Fridman

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 173-80

A new torsional viscometer is described, involving an outer hollow steel cylinder inside which a coaxial steel piston can be made to rotate with 0.1-0.2 mm clearance. Lower end of the piston carries a hard point resting on a glass plate. Piston rod can be set in rotating motion by means of thread wound around the head of the rod and weighted on both ends. Errors due to friction of the point on the glass plate and of the thread on its pulleys are small and constant. Measurement, which requires 2-3 ml of oil, consists in noting the time necessary for rotation by 360°. Apparatus responds to temperature variations of 0.1°. The load must be so chosen that rotation is completed within less than 300 sec; otherwise the temperature might vary by as much as 0.4-0.8°. Time of a complete rotation is inversely proportional to the load within 2%. Error is minimum if the load is so chosen that one rotation takes about 100 sec.

"Increase of Viscosity of Oils Under the Action of a High-Frequency Electromagnetic Field," G. M. Panchenkov, Gubkin Petroleum Inst, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 191-5

Frequencies of 12 - 100 megacycles were applied to samples of spindle oil, machine oil, and cylinder oil, for several hours. In all cases, the viscosity was distinctly increased, the more so the longer the exposure and higher the molecular weight of the hydrocarbons of the oil. Effect is stronger the shorter the wave length.

"Determination of the Viscosity of Lubricating Oils at Low Temperatures," Yu. A. Pinkovich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 181-9

Lee's mercury-column viscometer with slight modifications is adapted to low-temperature viscosity measurements on oils. Only initial values of the viscosity were determined, without preliminary heat-treatment. Times of flow were kept below 15-20 min. Capillaries of 1.5, 2.3, and 4 mm diameter, the latter used for highly viscous oils, gave differences not higher than 1.5%. From investigations of 13 aviation oils of

~~RESTRICTED~~

STAT

various origins, between  $+100^{\circ}$  and  $-25^{\circ}$ , it is concluded that, as a rule, the lower the  $\eta$  is at  $100^{\circ}$  and at  $50^{\circ}$ , the lower it is also at temperature below  $0^{\circ}$ ; this, however, is only correct for oils of the same origin, same purification, etc. Formation of crystalline skeleton and appearance of structure (anomalous increase in  $\eta$ ) is traced by comparing  $\eta$  measured under pressure and without pressure.

"Applicability of Philippoff's Equation and Graphic Method to the Extrapolation of the Viscosity of Consistent Greases," A. A. Konstantinov, Gubkin Petroleum Inst, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyarkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 211-14

Varentsov's procedure for determining limiting viscosities of consistent greases was tested with the aid of the experimental data of Arveson obtained at various rates of shear. Curves plotted in the logarithmic coordinate system for lime soap greases cannot be made to coincide with Philippoff's parameter line by either vertical or horizontal displacement. Experimental values of  $\eta$  in terms of  $v$  are compared with  $\eta_{\infty}$  and  $\eta_0$  calculated analytically from the Philippoff's equation. The calculated minimum  $\eta_{\infty}$  is somewhat higher than the experimental figure at high  $v$  at both  $+25^{\circ}$  and  $-17.8^{\circ}$ . However, the experimental  $\eta$  at very low  $v$  at both these temperatures is many times higher than the extrapolated  $\eta_0$ , which theoretically is the maximum possible value. With regard to the minimum viscosity  $\eta_{\infty}$ , the error committed in applying the Philippoff's extrapolation is the more serious the lower the rates of shear at which the data were obtained.

"Application of Viscometry to the Characterization of Properties of Consistent Greases," V. P. Varentsov

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyarkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 197-210

From measurements with Scott-Blair horizontal-capillary viscometer with manostat and manometer, the shearing stress  $P$  and the rate of shear  $v$  were calculated by the relations  $P = pR/2l$  where  $p$  = pressure,  $R$  and  $l$  are, respectively, radius and length of capillary, and  $v = 4Q/\pi R^2$ , where  $Q$  = rate of efflux, or  $v = l/\pi RT$ , where  $T$  = time of efflux in seconds. In accordance with the procedure indicated by Philippoff incidence of experimental points for various  $R$ ,  $l$ , and  $p$  on one single curve (the "consistency curve") proves the flow to be laminar and stationary; graphic treatment of the data plotted in the logarithmic coordinate system  $P - v$

~~RESTRICTED~~~~RESTRICTED~~

RESTRICTED

STAT

permits the determination of  $\eta_0$ ,  $\eta_{\infty}$ , and  $\tau$  in Philippoff's equation  $\eta' = \eta_{\infty} + (\eta_0 - \eta_{\infty}) / [1 + 2/3 (P^2/\tau^2)]$  where  $\eta_0$  is the limiting constant viscosity on vanishing stress,  $\eta_{\infty}$  the limiting minimum viscosity on infinitely increasing stress, and  $\tau$  a constant termed the modulus of stress. The three magnitudes of  $\eta_0$ ,  $\eta_{\infty}$  and  $\tau$  characterize the viscous properties of the material.

"Mechanical Equivalent of the Internal Friction of Consistent Greases," D. S. Velikovskiy, Gubkin Petroleum Inst, Moscow

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 215-31

ASTM methods based on the penetration of a plunger do not yield a meaningful characteristic of the mechanical properties of greases. Constant-rate consistometric methods allow no distinction between limiting resistance to shear and internal friction. Mechanical equivalent of the internal friction can be determined, defined as the viscosity (in poises or stokes) of an oil having the same coefficient of internal friction as the given grease at equal rate of shear and load, or requiring the same amount of work to be dispensed along tubes of given length and diameter at the same rate. Such determinations for number of consistent greases were made with Dettmar's friction machine, at relatively high revolving speeds which at the given loads insured sufficient thickness of the grease film. For both oil and grease, curves of mechanical friction  $\mu$  against  $\omega$  (rpm) are plotted and the viscosity  $\eta$  of the oil giving the same  $\mu$  as the grease at the given velocity is read from the graph. Results are represented in the form of plots of  $E$  (mechanical equivalent of internal friction, in stokes), against  $\omega$ . Results of investigation of various types of grease are described.

"Determination of the Viscosity of Standard Oils for the Calibration of Viscometers," Yu. A. Pinkevich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 233-8

Of the organic liquids proposed, only aniline gives accuracy of about 1% but is unfit for calibration of viscometers with capillary diameter over 1 mm such as are needed for measurements on higher viscosity oils. Water is proposed as standard liquid for calibrations. At two standard temperatures, 20.00° and 25.00°, the dynamic and kinematic viscosities  $\eta$  and  $\nu$  are taken to be, respectively,  $\eta = 1.0050$  and  $C.89485$  centipoise and  $\nu = 1.0067$  and  $0.89748$

~~RESTRICTED~~

STAT

centistokes. Two Ostwald-Fenske viscometers and a time meter use, are described. Purification of the standard oil is described, and method of calibration presented.

"Viscosity of Blast-Furnace Slags," I. P. Semik,  
Metal Inst, Acad Sci USSR

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 257-69

Four initial ternary slags of different compositions are investigated. The meter is of the rotating-spindle type, suspended on an elastic steel wire. Lower limit of accuracy is 0.2 poises. Upper limit of viscosity, at the given speed of rotation is about 70 poises. Viscosity measurements of the four initial slags are given. Effects of addition agents are also described. In general, additions of alkali to the extent of 2 - 4% have slight viscosity-lowering effect on acidic slags and no effect on basic slags. "liquefying" action of alkalis on basic slags is no greater than the effect of CaO as found by MacCaffery. Observations showed that the surface layer of fused slags has anomalous viscosity. In particular, readings differ according to the depth of immersion of the rotating spindle. Anomaly exists not only at temperatures close to the temperature of solidification, where the limiting shearing stress is particularly high, but even at higher temperatures. It would appear that even above freezing temperature a thin surface layer behaves like a crystalline solid. Chemical analysis failed to show any difference in composition for the surface layer as compared with the bulk of the liquid.

"Viscosity of Titanium-Containing Slags," L. V. Zverev

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved,  
Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov"  
Vol I, 1941, pp 271-7

Slags rich in  $TiO_2$  occur in the extraction of iron from titanomagnetite ores. Contrary to often-expressed views, the  $TiO_2$  content does not give rise to abnormally high viscosity. With modified Volaro-cich high-temperature viscometer, with coaxial cylinders, the lower limit of accuracy could be brought to 1 poise; measurements on acidic slags showed the viscosity to be function of the  $SiO_2$  content. There is only insignificant variation up to about 35%  $SiO_2$ ; from that interval on, further increase in  $SiO_2$  is accompanied by sharp increase in viscosity. Nine typical  $TiO_2$ -containing slags were measured in apparatus based on damping of oscillations, and suitable for viscosities of the order of tenths of a poise.

STAT

Examples are given. All curves have the typical shape of viscosity curves of crystallizing melts, with a very small viscosity gradient above a certain temperature and sharp rise of the viscosity below that temperature. All slags show very low viscosities, of the order of tenths of a poise, above that temperature. It is not clear as yet how far this temperature of beginning "thickening" corresponds to the temperature of actual crystallization.

"Viscosity of Slags of Nonferrous Metallurgy," G. I. Damskaya

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 295-305

Viscosities were determined in steel rotating-coaxial-cylinder apparatus. Owing to some interaction with the crucible walls, the slags after fusion were found to contain about 1-2% FeO more than initially. Slags from various Cu-production plants, Cu content ranging from 0.21% to 1.45% SiO<sub>2</sub> 20-37, FeO 40-60, CaO 0.5-7.7%, and varying amounts of Al<sub>2</sub>O<sub>3</sub>, MgO, SnO, BaO, S, showed between 1,050° and 1,250°  $\eta$  from 6 to 42.5 poises. Viscosities of Kirovgrad converter slag and strongly acidic slag from the Korsakpayskiy plant are determined. Slags from nickel-producing plants, ranging from 34 to 45% SiO<sub>2</sub>, 13.8-19.9% FeO, 20-31% CaO, 7.3-11.9% Al<sub>2</sub>O<sub>3</sub>, with 0.13-0.40% Ni are considerably more viscous than the copper-production slags. Five different slags from two lead-producing plants are characterized by relatively low SiO<sub>2</sub> content, low Al<sub>2</sub>O<sub>3</sub>, FeO, and CaO content, and high ZnO. Owing to interaction between the latter and the steel crucible, no viscosity determinations can be made above 1,250°, also measurements on slags with more than 10-11% ZnO are unreliable. Lead slags investigated (1.5 to 3.8% Pb) between 1,250° and 1,675° have  $\eta$  between 3 and 30 poises.

"Viscosity of Fused-Silica Glass," N. V. Solomin, Moscow Glass Mfg Plant Lab, Peoples Commissariat Elec Industry

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 317-25

Measurements were made with coaxial-cylinder apparatus in carbon crucibles, which apparatus is described. Method of determinations is presented. Protracted measurements at 1,940° proved that no change occurred in one hour. Microscopic determination of the volume

~~RESTRICTED~~

STAT

and surface area of the gas bubbles occluded in the fused  $\text{SiO}_2$  showed the bubbles to occupy 1.95% of the volume and 0.23% of the section of the glass. Viscosity at temperatures of 2,000, 1,940, 1,880, 1,800, and 1,720° are given. From the values of viscosity, the molecular weight  $M$  of the  $(\text{SiO}_2)_n$  aggregates in fused and in softened  $\text{SiO}_2$  glass was calculated, the formula of which is given. It was found that the size of  $(\text{SiO}_2)_n$  aggregates and the tetrahedral arrangement of Si and O atoms account for both the high chemical stability and viscosity of  $\text{SiO}_2$  glass. Introduction of metal oxides, resulting in considerable lowering of the viscosity, obviously indicates disruption of the aggregates and reduction of their size.

"Viscosity of Electric Bulb Glass of Various Compositions," B. M. Fromberg, Z. N. Tsyplenkova, B. V. Rabinovich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 341-51

In the region of softening, the  $\eta$  is determined by microscopic reading of the elongation of rod of the given glass, suspended on a nichrome wire, under different loads. In the region of fusion, a modified Volarovich rotating coaxial cylinder, both closed and open cylinder type, method is used. The two apparatuses and the conditions of determination are described. As Pb-free glass for use in manufacture of incandescent lamps, a dolomite glass,  $\text{SiO}_2$  69.0,  $\text{MgO}$  3.5,  $\text{CaO}$  5.5,  $\text{BaO}$  5.0,  $\text{K}_2\text{O}$  4.0,  $\text{Na}_2\text{O}$  13.0% ("BD-1") was found suitable on a production scale and is recommended. Systematically investigated were PbO-dolomite,  $\text{AnO}$ -dolomite,  $\text{BaO}$ -dolomite,  $\text{K}_2\text{O}$ -dolomite,  $\text{Na}_2\text{O}$ -dolomite glasses. Percentage compositions of each are given. Curves of  $\log \eta$  against temperature are drawn for each type. From plots of temperature of equal  $\log \eta$  against composition ( $\text{RO} = \text{PbO}, \text{ZnO}, \text{BaO}$ , or in  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ ) it is concluded that exchange of  $\text{SiO}_2$  for  $\text{RO}$  lowers  $\eta$  at all temperatures; this  $\eta$ -lowering effect of increasing amounts of  $\text{RO}$  is more pronounced in the region of low  $\eta$ ; Pb and Ba glasses have the closest  $\log \eta$ -temperature curves, those for Zn glasses deviate therefrom to a greater extent;  $\text{K}_2\text{O}$ - $\text{Na}_2\text{O}$  glasses show no minimum at any composition ratio, contrary to Gehlhoff and Thomas; exchange of  $\text{Na}_2\text{O}$  for  $\text{K}_2\text{O}$  raises  $\eta$  gradually and slowly but the effect is negligible up to 4%  $\text{K}_2\text{O}$ .

"Viscosity of Nonsilicate Glasses," F. P. Oshchikov, B. V. Rabinovich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 353-7

~~RESTRICTED~~

~~RESTRICTED~~

STAT

Glasses used for high intensity Na-vapor bulbs are investigated. Viscosities,  $\eta$ , were determined between 450° and 1,250° with rotating-coaxial-cylinder apparatus for four types of glass, all containing  $B_2O_3$  57.0,  $Al_2O_3$  20,  $CaO$  6.0,  $BaO$  5.0%; and varying amounts of  $K_2O$  and  $Na_2O$ . For comparison silicate glass was also determined.  $\log \eta$  (from graph) at 500°, 700°, and 900° for each type are given; temperature intervals corresponding to doubling of  $\eta$  are also given. All  $\log \eta$ -temperature curves have the same shape, rising steeply with falling temperature; only the  $B_2O_3$  curve runs more smoothly. Plots of lines of equal  $\eta$  in the system temperature against  $K_2O$  ( $Na_2O$ ) content (isocomes) represent series of nearly parallel curves with slight minimum. In general, exchange of  $Na_2O$  for  $K_2O$  affects of nonsilicate glasses much less than in the case of silicate glasses.

"Viscosity of Disperse Systems and Structure Formation," P. A. Rebinder

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 361-80

Critical review, particularly of Russian work.

"Viscosity of Peat Suspensions," N. N. Kulakov, Moscow Peat Inst

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 391-403

(1) Horizontal-capillary viscometers suitable for peat suspensions and the conditions for measurement are described. It was confirmed that peat suspensions in water conform to Bingham's model of a plastic-viscous body, the limiting shearing stress  $\theta$  and the Bingham viscosity  $\eta$  being constant and independent of the dimensions of the capillary. With rising temperature, between 8° and 50°, both  $\theta$  and  $\eta$  decrease; the latter decreases more slowly than the true viscosity of pure water. Decrease of  $\theta$  is more pronounced than that of  $\eta$ ; from 8° to 50° falls to half its original value. The same effects are observed with certain additions. Aging of the suspensions is indicated by the spontaneous increase in both  $\theta$  and  $\eta$ . (2) Results obtained with the capillary viscometer were compared with those for the same peat suspensions by two other methods; a rotating type viscometer in which an inner coaxial cylinder is made to rotate under the action of a falling load; and by Skryabin's method measuring the rate of ascension of a hollow, conveniently weighted sphere, coupled with Stokes' equation involving corrective magnitude  $\Delta$  (difference

~~RESTRICTED~~

~~RESTRICTED~~

STAT

of diameter of suspension and sphere at which the ascension first becomes noticeable);  $\Delta$  is assumed to be proportional to  $\Theta$ . Preliminary experiments with normal Newtonian liquids demonstrated the identity of results obtained with the three methods. This does hold for suspensions of the type of peats in water, however. (3) Data on industrial-scale flow of peat suspensions check satisfactorily with Harrik's formula linking yield in liter/second with the loss of pressure  $P$  (kg/sq cm) along 1,000 meters of pipe, diameter  $D$  (cm) of the pipe and  $\eta$  (kg/sq cm.) Formula was further checked by determinations of the profile of velocity distribution in the pipes, by adding an electrolyte and measuring the electric current at various spots.

"Viscosity of Mazut Coal Suspensions," V. F. Kustov, L. L. Khotuntsev, Disperse Fuel Lab, Energetics Inst., Acad Sci USSR

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol. I, 1941, pp 405-13

Samples include suspensions in commercial mazuts of charcoal, grain size 45 and 75  $\mu$ , solid phase content 10%, 15%, and 20%, and of coal powder, grain size 44, 74, and 100  $\mu$ , solid content 20%, 30%, 40% and 50%. Measurements were made in horizontal-capillary viscometer. Laminarity of the flow was confirmed. From plots of the viscosity  $\eta$  against the pressure it was ascertained that the limiting shearing stress is practically zero and can be disregarded. With 30% coal suspensions,  $\eta$  drops sharply with rising temperature, from 20° to 80°, where the curves for various samples seem to converge. Shape of the  $\eta$ -temperature curves is determined primarily by that of the oil used. Charcoal suspensions show, below 80°, higher  $\eta$  than suspensions of coal of equal content (20%); this is ascribed to higher adsorption capacity and resulting immobilization of larger amounts of the liquid medium. For both coal and charcoal suspensions,  $\eta$  rises sharply with increasing content of solid phase. At ordinary temperatures the suspensions lose their fluidity at about 50% solid phase. Effect of grain size is slight. Homogenization of the suspensions by repeated passing through colloidal mill, without change of grain size, results in markedly lower  $\eta$ . This is due only to higher degree of homogeneity, not to higher dispersity.

"Lowering of the Viscosity of Clay Suspensions," V. S. Baranov

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 415-25

~~RESTRICTED~~



STAT

~~REDACTED~~

Filtrability and viscosity of water suspensions of bentonite clay were investigated in terms of the action of viscosity-lowering agents, in view of practical problems in oil drilling. Three classes of reagents are studied, brown coal-caustic soda, vegetable tannic extract-caustic soda, sulfite cellulose extract-caustic soda. Viscosity determinations were mainly relative, using funnel-shaped viscometer. Effects of the addition of reagents of various compositions on both filtrability and viscosity are plotted in the form of triangular diagrams in terms of percentage brown coal-NaOH-water. Optimum composition appears to be 15.0 gr brown coal, 2 gr NaOH in 100 cc of reagent. Analogous diagrams for tanning extract-NaOH-water show the optimum ratio to lie at 1:0.6. The reagent sulfite cellulose-NaOH-water lowers the viscosity and increases the filtration value at all compositions. Specifically, it is found that the tendency to increased viscosity depends directly on the quantitative content in Na; the filtration-lowering effectiveness of reagent on given clay is function of its Ca + Mg content. Clays are classified and ordered in series from this point of view and optimum recipes of filtration- and viscosity-modifying agents discussed.

"Viscosity of Higher Fatty Acids and Fats," G. B. Ravich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 427-40

"Viscosities  $\eta$  measured with an average error of 0.5% in a capillary Ubbelohde-type viscometer under 40-60 mm Hg pressure, between 20° and 100°, of fat acids  $C_{18}$ , namely, linolenic, linoleic, oleic, and stearic acids and their mixtures, plotted in terms of the iodine number, give straight-line isotherms converging toward point at about  $I = 400$ ,  $\eta = 2$  centipoises; at each temperature,  $\eta$  decreases linearly with increasing  $I$ , the more steeply the lower the temperature. Tristearin, tristearin, and tripalmitin show higher  $\eta$  than the corresponding acids. Viscosities of natural fat oils -- sunflower (liquid and hardened), linseed, cottonseed, rape, mustard, castor oil, seal blubber -- between 0° and 90° also follow an exponential law. Progressive hydrogenation brings about steady increase in  $\eta$ ; the curve is very nearly the mirror image of the curve of simultaneously decreasing  $I$ ; the curve of density in terms of time of hydrogenation is very nearly parallel to that of  $I$ . Viscosity anomalies of natural fat oils were investigated by way of variation of the pressure  $P$ . The effect of shortwave irradiation on viscous anomaly of castor oil was found to be negligible after an exposure of 90 min; however, after 180-min irradiation value of  $\eta$  dropped with an increase of  $P$ .

~~REDACTED~~

~~RESTRICTED~~

STAT

"Viscosity in Mixtures of Oxides Forming Slags in Steel Production," P. P. Kozakevich, S. P. Leyba, E. P. Komar, Phys-Chem Lab, Kharkov Metals Inst

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 279-94

Two fundamental systems,  $\text{FeO-CaO-SiO}_2$  and  $\text{FeO-MnO-SiO}_2$ , are investigated. Rotating-coaxial-cylinder type viscometer, using cylinders of soft iron, is described; conditions for determinations are outlined. Calibration of the viscometer was done with castor oil, glycerol, and solutions of sucrose in glycerol, previously standardized by the falling sphere method. In the ternary system  $\text{FeO-CaO-SiO}_2$ , 105 slags of various compositions were measured and plotted isothermally ( $1400^\circ$ ) in a triangular diagram, between 50 and 100%  $\text{FeO}$ , 0-50%  $\text{CaO}$ , 0-50%  $\text{SiO}_2$ . This region of the triangle is taken up by lines of relatively low  $\eta$  (from 0.2 to 4-5 poises). Lines of lowest  $\eta$  lie closest to the  $\text{FeO}$  apex; a viscosity "barrier" that is region of steep increase of  $\eta$  with increasing content is situated toward the  $\text{SiO}_2$ - $\text{CaO}$  side, the increase being steeper in the direction of the  $\text{CaO}$  apex than in that of increasing  $\text{SiO}_2$ . The  $\eta$  diagram shows no maximum at the composition  $\text{FeO.CaO.SiO}_2$  (monticellite); however, at that composition, the 0.5- and 1-poise lines are more distant than elsewhere, which in a space model would correspond to a horizontal step in the slope falling toward  $\text{FeO}$ . In the system  $\text{FeO-MnO-SiO}_2$  (93 slags investigated) the mixtures accessible to measurements in an Fe apparatus is considerably wider than in the foregoing system. Lines of lowest  $\eta$  are again situated closest to  $\text{FeO}$ , and the viscosity "barrier" is much steeper in the direction of  $\text{MnO}$  than in that of  $\text{SiO}_2$ . In slags of the acid Martens process, replacement of  $\text{FeO}$  by  $\text{MnO}$  causes significant thickening only at relatively low contents of  $\text{SiO}_2$ , less than 30-50 molecular %; in slags very poor in  $\text{SiO}_2$ , 10-15%, replacement of even 20-25%  $\text{FeO}$  by  $\text{MnO}$  causes sharp increases in  $\eta$ . Investigation of the effect of  $\text{TiO}_2$  on the system  $\text{FeO-CaO-SiO}_2$  and  $\text{FeO-MnO-SiO}_2$  showed the "thinning" effect of  $\text{TiO}_2$  to be the more marked, the more acidic the original slag. Thinning effect of  $\text{TiO}_2$  is more pronounced in systems with  $\text{CaO}$  than with those containing  $\text{MnO}$ .

"Viscosity and Structure of Concentrated Solutions of Casein," P. F. D'yachenko

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyaskosti Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 447-55

~~RESTRICTED~~~~RESTRICTED~~

~~RESTRICTED~~~~RESTRICTED~~

STAT

Concentrated (15-34%) solutions of casein in aqueous NaOH (0.200 and 0.175 gram equivalent per 100 gr casein), investigated in Volarovich's rotating-coaxial-cylinder viscometer, show strictly linear dependence between the angular rate of rotation  $\omega$  (0-1.2/sec) and the load  $P$  (0-100 gr). Plot of  $\omega$  against  $P$  consists of group of straight lines radiating from common origin on the  $P$  axis, the intercept corresponding to the minimum load necessary to overcome the friction in the bearings of the apparatus (1-1.5 gr). It is thus demonstrated that at the given  $\omega$  the structure of the solutions is not perturbed. Systematic experiments were made with solutions in warm alkali at 40° for 2.5 hrs. Measurements of  $\eta$  on solutions containing 12-34% casein, in NaOH,  $\text{NH}_4\text{OH}$ , and  $\text{Ca}(\text{OH})_2$  at 18°, were computed by  $\eta = KP/\omega$ , where  $K$  = apparatus constant = 3.65.

Viscosity of Bitumens," N. N. Korotkevich

"Akad Nauk SSSR, Otdel Tekh Nauk, Inst Mashinoved, Soveshchan Vyazkost i Zhidkost i Kolloid Rastvorov" Vol I, 1941, pp 458-62

Three samples of bitumens, Baku petroleum No 1, No 3, and natural Shugurov, were investigated in rotating-coaxial-cylinder apparatus, the dimensions of which are given. Viscosity  $\eta$  is computed by the formula  $\eta = KP/\omega$ , where  $P$  = load in grams,  $\omega$  = number of revolutions per second, and  $K$  = apparatus constant. With the bitumens investigated, the proportionality between  $P$  (0-250 gr) and  $\omega$  (0-2.7/sec) holds for temperatures from 100° down to 60°; below that, at 50° and 40°, the lines are slightly curved. Measurements of  $\eta$  give curves nearly horizontal down to about 70°; below 60°  $\eta$  rises sharply with falling temperature. Bitumens behave as Newtonian liquids only at temperatures at which they are in the dropping liquid state; they deviate from that behavior and take on a plastic-viscous character from about 50° down.

- END -

- 27 -

~~RESTRICTED~~